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Why Manufacturing Firms Produce Some Electricity Internally

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A model explains the observed behavior — prevalent in Nigeria, common in Indonesia, rare in Thailand — that private manufacturing firms supplement their purchases of publicly produced electricity with electricity produced internally. In Indonesia and Nigeria, smaller firms would pay much more for publicly supplied electricity than larger firms would. Instead of giving quantity discounts, public monopolies should charge the larger firms more and the smaller firms less than they now charge, to encourage large firms to produce more of their own electricity.

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Summary findings

Many manufacturers in developing countries produce their own electricity because the public supply is unavailable or unreliable.

Lee, Anas, Verma, and Murray develop a model of the firm in which electricity is produced internally, with scale economies. The model explains the observed behavior (prevalent in Nigeria, common in Indonesia, and rare in Thailand) that firms supplement their purchases of publicly produced electricity with electricity produced internally.

To prepare an econometric estimate, they specify a translog model. In Nigeria, where firms exhibit excess capacity, generators are treated as a fixed input, whereas in Indonesia, where firms are expanding, they are variable.

They confirm strong scale economies in internal power production in both Nigeria and Indonesia. Shadow price analysis for both countries shows that smaller firms would pay much more for public power than larger firms would. Instead of giving quantity discounts, public monopolies should charge the larger firms more and the smaller firms less than they presently charge.

In Nigeria, the large firms would make intensive use of their idle generating capacity, while in Indonesia they would expand their facilities.

In both countries, small users would realize savings by having to rely less on expensive endogenous power.

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PREFACE

This report is part of a series of project reports (see the list below) produced within the research project, "Infrastructure Bottlenecks, Private Provisions, and Industrial Productivity: A Study of Indonesian and Thai Cities," which was jointly funded by the World Bank Research Committee (RPO 676-71) and USAID, Jakarta. Under the overall direction of Kyu Sik Lee, the study was jointly conducted with a research team headed by Chalongphob Sussangkarn at Thailand Development Research Institute, Bangkok, and a team headed by B.S. Kusbiantoro at Institute of Technology Bandung.

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I. INTRODUCTION

Most developing countries are characterized by deficiencies of various degrees in the infrastructure services produced and delivered by the public sector. Deficiencies are observed in electricity, water, telephone service, transport services and waste disposal.

In rapidly growing countries (such as those of the Pacific Rim), deficiencies occur because the rapid growth in the demand for infrastructure congests the capacity of the public sector to deliver services of a uniform quality. Elsewhere (as in Sub-Saharan Africa) deficiencies can be due to a combination of rapid growth in urban areas and a lack of equipment, spare parts and adequately trained personnel in the public sector.

Firms can adjust to infrastructure deficiencies in a number of ways. Perhaps, the most obvious form of adjustment is that a business remains "captive" to the inadequate public service, incurring the higher costs associated with the unreliability of such service. A second type of response occurs when the firm tries to achieve self-sufficiency by producing their entire infrastructure need within the plant. Usually, such a firm incurs a much higher unit cost because it cannot match the scale economies which are available to the public sector.

A third and more interesting response entails a compromise between "captivity" and "self sufficiency". In the case of electric power, the firm <u>blends</u> two types of power : the public power source which is cheap but of lower quality (e.g. subject to more voltage fluctuations) and its own in-house power which is more expensive but of a higher quality.

Households, as well as firms, must choose how to adapt to infrastructure inadequacies. Like firms, households can choose among remaining captive to inadequate public service, opting for self-sufficiency, and blending public and own provision. For example, in Nigeria, in the case of electricity, most households opt for captive status, and few for self-sufficiency, but a surprisingly large proportion of wealthy households opt for blending, buying power generators for use when the public service fails.

For the theoretical framework and econometric analysis in this study, we concentrate on the power sector and on firms' behavior. The general analytical and policy implications are, however, also relevant to other infrastructure sectors and, with more extensive adaptation, to household behavior.

The extent of internal generation of power varies among firms and is related to their production technologies. Two most important reasons for producing electricity endogenously are the uncertainty about power outages and the fluctuations in the voltage of public power which can cause damages to plant, equipment, intermediate inputs and output in the assembly line. To minimize this problem, if not solve it completely, blender firms produce their own power to either substitute or supplement the public supply. The endogenously generated power is used to "boost" the power supply obtained from the public sector smoothing out voltage fluctuations in the public supply <u>or</u> it is used to supply the plant when the public power source is interrupted.

When firms combine publicly provided and privately produced power to meet their own needs, a number of interesting policy questions arise about the optimal behavior of the public sector. When public sector deficiencies cannot be eliminated in even the medium term due to financial, cultural and technical constraints (as is the case in numerous LDC's), what are the infrastructure policy instruments that can be used to enhance the productivity of businesses and manufacturers ? Clearly, it may be optimal for the public sector to encourage some degree of endogenous infrastructure in the private sector, since an expanded capacity or more intensive use of existing idle capacity in the private sector reduces the demands placed on the limited capacity in the public sector. Reduced demands on the public sector, in turn, mean that congestion is reduced and that the quality and efficiency of the public sector infrastructure service is improved.

At a more practical level, when public power cannot be efficiently provided, how should the public sector encourage private production of power? What is the optimal allocation of public power among the various users who differ according to their ability to generate power privately? Who should receive priority in the allocation of electricity, large users, or small?

The correct answers to these questions must take into account a number of observations. First, publicly provided power is limited in both quantity and quality. Second, different users will differ in what they are willing to pay for public power at the margin. Large firms, having installed large generating capacities of their own, will have little to gain from improvements in the public power supply at the margin. Smaller firms will find it too expensive to produce their own power (because of the high fixed costs) and will be willing to pay considerably for additional public sector power and for public supply improvements. An appropriate policy response would be to reallocate the use of public power from the larger users to the smaller ones. Since pricing is the most efficient means for reallocating a limited resource and since users decide on quantity purchased by considering the price they are charged at the margin, it is questionable whether power suppliers in developing countries should continue to offer quantity discounts. Such discounts favor larger users and discriminate against smaller users. To allocate the limited power supply more efficiently, it may be optimal to impose increasing block tariffs.

The conflicting costs and benefits from such a revised pricing policy are as follows.

There is a direct benefit as larger users are induced to buy less public power and to utilize private power generators at costs only somewhat higher than the public sector's. While this increases the power use and costs of large users, such increases in costs can be more than offset by the savings realized by the smaller users. Since these smaller users are offered lower marginal prices, they increase their use of public power, reduce their costly reliance on their own generators and become more productive. There is also an indirect benefit which depends on whether the total power purchased from the public sector decreases. If so, given the fixed public transmission capacity, the reduced load relieves the level of congestion and improves the quality of the power delivered to firms.

The main focus of this paper is to provide quantitative support for the above observations, using data from Nigeria and Indonesia. For Nigeria, we rely upon a survey of 179 Nigerian manufacturers conducted in 1988. 89.4%, or 160, of the firms sampled were blenders of public and privately generated power. In aggregate, these firms supplied 32% of their power needs from their own generators, with this percentage varying among the firms from a mere 0.14% to a high of 96%. We also observed that these firms had installed a great deal of power generating capacity but did not utilize it fully. On the average 25% of the installed capacity was reported as utilized, the rest being kept in reserve for extreme power outages or as "insurance" against further deteriorations in public power. For our econometric work, we use 131 blending firms that bought and used non-negligible amounts of electricity and for which we had clean data.

For Indonesia, we rely upon a survey of 290 Indonesian manufacturers. 59% of the firms sampled were blenders of public and private power. In aggregate, these firms supplied 47% of their power needs from their own generators, from a mere 0.1% to a high of 99.9%. Of these 171 firms that blended public and private electricity, 30 firms generated 1000 kilowatt hours per year or less, too little to be much more than "warming up" their generators from time to time. Our empirical analysis is restricted to 118 firms that produced and bought non-negligible amounts of electricity and for which we had clean data.

We supplement the econometric analyses of Nigeria and Indonesia with data from Thailand, a country where hardly any firms produce their own electricity. We rely on a survey of 300 Thai manufacturing firms, only 18 of whom had their own electricity generators; we estimate scale and price elasticities for the 250 Thai firms that did not produce their own electricity and for which we had clean data.

Nigeria, Indonesia, and Thailand offer a spread of power infrastructure climates. In Nigeria, the government has enforced a strict government power monopoly despite severe inadequacies in the quality of the public supply of electricity, forbidding sales of electricity across firms and making costly firms' investments in their own generating capacity. In Indonesia, government has a monopoly on power transmission, but the inadequacies in the quality of public provision are less severe than in Nigeria. Moreover, Indonesian firms have recently been allowed to sell electricity to one another, and the cost of generators to firms have been reduced of late by reductions in import duties and tariffs. In Thailand, the government monopoly on electricity sales has not led to such poor quality that firms seek to produce electricity for themselves.

Nigeria, Indonesia, and Thailand also offer contrasting economic climates. The longstanding economic boom in Thailand, more recent boom times in Indonesia, and the persistent stagnation of the Nigerian economy each presents policy makers with a different environment in which to make public infrastructure decisions. Consequently, even though Nigeria and Indonesia share some common infrastructure problems, the appropriate policy responses differ between them.

The empirical approach we take for Nigeria and Indonesia is to model the production process of firms by means of country-specific translog cost functions in which the inputs of electricity are a mix of endogenously determined quantities of own power, and quantities purchased from the public sector. We estimate such models using our small samples of 160 and 141 blending firms which differed widely in their scale of operations, in their industries and in their locations within Nigeria and Indonesia. We then use the estimated model to calculate the shadow prices of purchased electricity. We found that in both Nigeria and Indonesia smaller firms would be willing to pay much for additional publicly provided electricity than would larger firms. These findings, suggest the Nigerian Electric Power Authority (NEPA) and its Indonesian counterpart, PLN, might improve efficiency by "tilting" the tariff against firms that purchase larger quantities of electricity (i.e. offering increasing blocks tariffs), thus inducing them to use their idle capacities and reducing congestion. (Firms that purchase more electricity tend also to be larger firms overall.) In fact, we believe increasing block price electricity tariffs would improve economic efficiency in Nigeria. But we are slow to recommend a similar policy in Indonesia because it is likely that the Indonesian economy's longer term response to the current economic boom is likely to overcome the infrastructure deficiencies reported by our sample of firms. This contrasts with the case of Nigeria, where chronic infrastructure deficiencies have long been, and are likely to remain, the rule.

In most studies of the firm in developed countries where public infrastructure systems are not the constraining factors, the production and cost functions are usually specified without variable inputs such as power and water, unless the purpose of the study is to measure the substitution elasticities between these infrastructure inputs and other inputs. Such studies are those by Berndt and Wood (1975), Griffen and Gregory (1976), Christensen and Greene (1976) and Pindyck (1979).

In the productivity literature [see Berndt and Christensen (1973), Denny and Fuss (1977) and Stevenson (1980)], cost functions are widely preferred over production functions because cost functions are easy to estimate, even when variable returns to scale are assumed. Hence, in section II we begin by developing a general theoretical model of the firm's cost minimization problem with the two types of electricity entering as separate inputs with private electricity production embedded in primary production. This model shows how the firm chooses to blend the two types of electricity given that each is nonlinearly priced : the endogenously generated electricity is subject to scale economies and, hence, has declining marginal cost while that purchased from public providers is subject to a quantity discount.

In section III we discuss, in general terms, translog econometric specifications of our theoretical models. In section IV, we present estimates for Nigeria and Indonesia in which the embedded cost function for electricity and the primary cost function are both specified in translog form. In both countries, the primary cost function is conditioned on both purchased (public sector) electricity and on the firm's capital stock; hence the cost functions are "restricted" cost functions. The embedded cost functions estimated differ between the two countries. Electricity generators are taken as fixed in Nigeria, where there is widespread excess capacity, and as variable in Indonesia where firms are generally expanding and generators are widely marketed. The estimated cost functions confirm the presence of strong scale economies in embedded production. A translog primary cost function for Thailand is also reported. As in Nigeria and Indonesia, capital is held fixed, but in Thailand, purchased electricity is a variable input and there is no embedded electricity production in the model.

Analyses of the shadow prices of purchased electricity are also presented in section IV. Because of strong quantity discounts in NEPA's tariff, small firms pay much larger marginal prices for public electricity than do large firms. We estimate that small firms have markedly higher shadow prices for electricity than do large firms. If NEPA and PLN were to charge the largest firms more and the smaller firms less than they currently charge, more electricity would become available to those who are willing to pay the most for it. This is the opposite of current practice in which the NEPA and PLN set declining block price tariffs. The optimality of increasing block tariffs for both Nigeria and Indonesia was confirmed in simulations reported in Anas and Lee (1995). However, the economic benefits of switching from the current tariffs to the optimal ones varied considerably between the two countries. On the one hand, in Nigeria, the total cost of production among the sampled manufacturers plus the cost of publicly provided electricity decreased from 4% to 9%, depending on the assumptions of the simulation. On the other hand, in Indonesia, the comparable decreases in cost were from 0.01% to 0.06%, which are negligible.

In Nigeria, a more efficient strategy of higher prices for purchasers of more electricity would induce NEPA's largest customers to make more intensive use of their idle generating capacities. In Indonesia, such a policy would spur larger users, who are more efficient power producers, to expand their generating facilities and smaller users, who are less efficient power producers, to contract theirs. In both countries, as large users switched to their own generators, congestion on the transmission network would be reduced and the quality of the public power delivered to the smaller users would improve. Small users would, in turn, realize savings by having to rely less on expensive endogenous production of electricity. However, in Indonesia, where rapid economic growth is already spurring government to markedly improve its public infrastructure provision, incentives to expand own-generating capacity, only mildly helpful in the short run, might prove quite inefficient in the long run. We therefore conclude that only NEPA in Nigeria should adapt an increasing block price tariff for publicly provided electricity.

We further encourage Nigeria to facilitate inter-firm sales of electricity, as Indonesia is doing. The marked economies of scale in production of own electricity suggest that smaller firms would do better to buy power from larger neighbors rather than invest in their own generating capacity. Section V concludes with a discussion of these policy recommendations.

II. THEORETICAL MODEL

As explained above, nearly 90% of the sampled manufacturing firms in Nigeria, and 59% of the sampled firms in Indonesia, were observed to consistently use both publicly supplied power and electricity they generated internally. The reasons why firms use the two sources of power differ widely among firms and are technological in nature. In some industries, critical functions require uninterrupted operation of the assembly line. Hence, internally generated power must be used immediately upon a failure in the public supply or else prohibitive damage results. In other industries, temporary shutdowns may be tolerable from a technological point of view (there is no damage to equipment) but are considered too uneconomical as most factors of production remain idle but are paid. In other cases, firms may decide to use their own power simply to moderate voltage fluctuations and improve the quality of their output.

In this analysis, we treat the inadequacies of NEPA's and PLN's electricity provision as an element of the underlying technology available to firms. Power interruptions and voltage surges force firms to use more of other inputs for any given output and quantity of NEPA or PLN electricity than would be the case if these public suppliers were technically efficient. In an effort to minimize the cost consequences of NEPA's or PLN's inefficiency, almost all firms supplement public electricity with their internally generated electricity. To explain the firms' own generating activity, we analyze Nigerian and Indonesian manufacturing technology in a model that includes an embedded production process for own electricity generation, as well as the consumption of electricity purchased from the public monopoly. Since our concern is with the private provision of infrastructure, we restrict our econometric model to only those firms using both sources of power. (This restriction justifies our econometric specification which assumes each type of power is an essential input.)

The notation of our theoretical model, to be explained below, is briefly summarized as follows:

Q : quantity of output produced by the firms's primary production process,

e : quantity of electricity produced internally (embedded production) and used as an input in primary production,

e_B : quantity of electricity bought from the public sector (NEPA or PLN) and used as an input in primary production,

$\mathbf{X}_o$: column vector of n input quantities such as labor, materials, capital (but not electricity) used in primary production,

$\mathbf{X}_e$: column vector of m input quantities (such as labor, materials and generators) used in endogenous (embedded) electricity production,

P : price of the firm's primary output,

$\mathbf{p}$: column vector of primary input prices,

$\mathbf{w}$: column vector of embedded input prices,

$t(e_B)$: the tariff cost for e_B units of publicly supplied electricity.

NEPA and PLN both give quantity discounts. Hence,

$\partial t(e_B)/\partial e_B > 0$ and $\partial^2 t(e_B)/\partial e_B{}^2 < 0$.

The firm's production function for the primary output is specified with two electricity variables:

$$(1) \qquad Q = Q(\mathbf{X}_o, e, e_B),$$

The production of own electricity, e, is specified by the embedded production function:

$$(2) \qquad e = e(\mathbf{X}_e)$$

We assume that the firm is competitive in both input and output markets. Such a competitive firm maximizes profit, π, as follows :

$$(3) \qquad \underset{\mathbf{X}_o, \mathbf{X}_e, e_B}{\text{maximize}}\ \pi = PQ(\mathbf{X}_o, e(\mathbf{X}_e), e_B) - \mathbf{p}'\mathbf{X}_o - \mathbf{w}'\mathbf{X}_e - t(e_B)$$

Equivalently, the above can also be written as :

$$(3') \qquad \underset{\mathbf{X}_o, e, e_B}{\text{maximize}}\ \pi = PQ(\mathbf{X}_o, e, e_B) - \mathbf{p}'\mathbf{X}_o - c(\mathbf{w}, e) - t(e_B)$$

where $c(\mathbf{w},e) = \mathbf{w}'\mathbf{X}_e^*$ is the cost function for embedded electricity production and gives the minimum cost of producing e units of electricity internally when the embedded input prices are

w. In other words, X_e^* solves the following cost minimization problem :

$$\text{Minimize } \mathbf{w}'\mathbf{X}_e, \text{ subject to: } e(\mathbf{X}_e)=e.$$

Given our data, it is easier to do empirical work with cost functions than with production functions. We choose, therefore, to treat firms as cost minimizers. The appropriate cost minimization problem is:

$$(4) \quad \underset{\mathbf{X}_o,\mathbf{X}_e,e_B}{\text{Minimize}} \ \mathbf{p}'\mathbf{X}_o + \mathbf{w}'\mathbf{X}_e + t(e_B)$$

$$\text{subject to: } Q = Q(\mathbf{X}_o, e(\mathbf{X}_e), e_B).$$

Or, using the cost function for embedded electricity, we can also write this as :

$$(4') \quad \underset{\mathbf{X}_o,e,e_B}{\text{Minimize}} \ \mathbf{p}'\mathbf{X}_o + c(\mathbf{w},e) + t(e_B)$$

$$\text{subject to: } Q = Q(\mathbf{X}_o, e, e_B).$$

It is easy to show that (4) and (4') are equivalent. On the one hand, because c(w,e) is the minimum cost of producing e units of power, $\partial e/\partial X_{oi} = w_i/\mu$, for each embedded input $i=1,\ldots,m$. μ is the marginal cost of the embedded output, e. On the other hand, from (4), $\partial e/\partial X_{ei} = w_i /[(\partial Q/\partial e)\lambda]$, where λ is the marginal cost of Q. Hence, for (4) and (4') to be equivalent, we need that $\mu = (\partial Q/\partial e)\lambda$. But this is clearly true, since the left side is the marginal cost of embedded power and the right side is the marginal product of embedded power times the marginal cost of the output.

We prefer to work with (4') since it is simpler. The Lagrangian function of (4') is :

$$(5a) \quad L = \mathbf{p}'\mathbf{X}_o + c(\mathbf{w},e) + t(e_B) + \lambda[Q - Q(\mathbf{X}_o,e,e_B)]$$

Maximizing (5a) with respect to $\mathbf{X}_o$, e, e_B and λ we obtain the first order conditions, which are:

$$(5b) \quad \partial L/\partial X_{oi} = p_i - \lambda(\partial Q/\partial X_{oi}),$$

(5c) $\partial L/\partial e \quad = \partial c(\mathbf{w},e)/\partial e - \lambda(\partial Q/\partial e)$,

(5d) $\partial L/\partial e_B \quad = \partial t(e_B)/\partial e_B - \lambda(\partial Q/\partial e_B)$,

(5e) $\partial L/\partial \lambda \quad = Q - Q(\mathbf{X}_o,e,e_B)$.

The Lagrangian multiplier λ is the shadow price of the output. When $\lambda = P$, the market price of the output, then (5b)-(5d) satisfy the condition of profit maximization that the value of the marginal product of each input equals its marginal cost.

Rates of technological substitution (RTS) between any pair of inputs are obtained from (5b) through (5d). They are :

(6a) $RTS(X_{oi},X_{oj}) = (\partial Q/\partial X_{oi})/(\partial Q/\partial X_{oj}) = p_i/p_j$, for any two primary inputs i and j,

(6b) $RTS(X_{oi},e) = (\partial Q/\partial X_{oi})/(\partial Q/\partial X_{oi}) = p_i/[\partial c/\partial e]$, for any primary input i,

(6c) $RTS(e_B,e) = (\partial Q/\partial e_B)/(\partial Q/\partial e) = [\partial t/\partial e_B]/[\partial c/\partial e]$.

(6d) $RTS(X_{oi},X_{ej}) = (\partial Q/\partial X_{oi})/[(\partial Q/\partial e)(\partial e/\partial X_{ej})] = p_i/w_j$, for any primary input i, and any embedded input j

Labor appears in both the primary and embedded production functions. However, since the skills required in the two settings may differ, the wage rates may differ between the two. Consequently, we treat labor in the two settings as distinct inputs.

It should be noted that NEPA and PLN quantity discounts and scale economies in embedded production (falling marginal costs of e and e_B) mean that the cost of power is concave in e and e_B which causes the isocost curve between e and e_B (keeping $\mathbf{X}_o$ constant) to be nonlinear and convex to the origin. However, as long as the isoquants are convex to the origin and do not cut the axes (because of our assumption that both e and e_B are essential inputs), the tangency between the isocost curve and the isoquant insures an interior solution. The TRS conditions (6c) implies the Marshallian equilibrium condition that the marginal products of the last naira or rupiah spent on each type of electricity are equal. Of course, the same is true for any pair of inputs and the optimal mix is determined by satisfying all of these conditions,(6a)-(6d), simultaneously.

The duality of production and cost implies that one can examine firms' technologies by estimating either their production functions or their cost functions. Since we have chosen to work with cost functions, examining returns to scale is particularly straightforward. However, the non-linearity of electricity input prices does pose a problem in cost or profit function estimation.

Maximizing 5a does not yield a traditional profit function because the electricity inputs do not have constant marginal (equal to average) prices. One cannot express costs as a function of a set of (constant marginal, equal to average) input prices and output. Similarly, there is not a traditional cost function corresponding to cost minimization for a given level of output as a function of input prices. However, for purposes of estimating the characteristics of the production technology and cost structure, one can instead use what Murray (1983) called a "mythical cost function" for the firm. We use this device in our estimation. In the mythical function, the firm's costs are recalculated as if marginal costs were the constant average cost for the firm. Murray shows that such a reformulation of the model does identify the underlying technology of the firm with behavioral data from cost minimizing firms facing non-linear input prices. The essence of the procedure can be seen by looking at (6b) and (6c): once the two marginal prices are evaluated at the observed electricity levels for the firm, those marginal prices enter the first order conditions just as constant (marginal-equal-to-average) prices would in a standard cost function.

A more specific model can now be developed by defining the firm's technology and setting an appropriate time horizon. Usually, economists think of the firm as having two time horizons, long run and short run. In the long run all primary inputs, capital, labor and raw materials would be variable, together with each type of electricity. In the short run, some inputs would be fixed. For our purposes, it is useful to think of two different short run cases; one in which all capital, including generators is fixed, and another in which primary production capital is fixed while generator capital is variable. Nigeria better fits the former sort of short run. Most Nigerian firms have considerable excess capacity, and operate with quantities of primary capital and generating capital that were chosen long ago. Indonesia better fits the latter sort of short run. Primary capital is not varied often, so the Indonesian firms we observe, few of which are new firms, did not settle upon their primary capital requirements recently; but generators are more easily added than some other capital equipment, like structures, and there appears to be an active market for generator sales to new and old firms alike.

We first specify the firms' embedded cost function in the fixed generators case, which we will apply to the Nigerian data. The embedded cost function takes the form:

$$(7) \qquad c(w,e;k) = c\,(w_l,w_m,e;k),$$

where w_l and w_m are the embedded input prices of labor and material, and k is the stock of generators. Variable embedded cost in this instance is labor costs plus materials costs. Because of expected scale economies in embedded production we expect $\partial c(w,e)/\partial e < c(w,e)/e$ (marginal cost is below average cost). The firm values embedded power at its marginal cost. Let p_e denote the price of embedded power, it is calculated from (7) as follows:

$$(8) \qquad p_e = MC_e = \partial c(w_l,w_m,e;k)/\partial e$$

When generators are treated as a variable input (as we shall treat them in the Indonesian case), w_k being the price of capital, the price of embedded power, p_e, then becomes:

$$(9) \quad p_e = MC_e = \partial c(w_l, w_m, w_k, e)/\partial e$$

The variable cost of embedded production in this case consists of labor cost, generator costs, and material cost. Again, we expect scale economies in embedded production. As we shall see below, the variable cost of primary production consists of the costs of labor and raw materials in primary production plus payments to NEPA or PLN and the cost of producing embedded electricity.

As was discussed above, electricity sold by either NEPA or PLN is also priced non-linearly due to quantity discounts in the tariffs with the marginal tariff price below the average tariff. Hence, letting p_B be the marginal cost of buying power from NEPA or PLN, it is calculated as:

$$(10) \quad p_B = MC_B = \partial t(e_B)/\partial e_B$$

The system of equations defining the firms's short run variable cost structure can now be written as follows in the case when generators are a fixed capital input in embedded production and primary capital, K, is a fixed input in primary production.

$$
\begin{aligned}
(11) \quad C(p,Q;K) &= C(p_L, p_M, p_e, p_B, Q;K) \\
c(w,e;k) &= c(w_l, w_m, e;k) \\
p_e &= \partial c(w,e)/\partial e \\
p_B &= \partial t(e_B)/\partial e_B
\end{aligned}
$$

Since neither p_e nor p_B are constants, (11) is not, strictly speaking, a traditional cost function. However, if the costs of electricity inputs are calculated as if the operative marginal prices were constant average prices, so that the costs are not observed costs, but "mythical" costs, as defined in Murray(1983), then (11) can be used as if it were a true cost function, the cost function that would apply if average (equal to marginal) prices were indeed constant. Such a mythical cost function suffices for calculating scale economies, shadow prices and input price elasticities.

III. ECONOMETRIC MODEL

(i) Translog Specification of Cost Functions

Since the firms in our sample belong to different industries, their technologies differ widely. The translog cost function [Christensen, Jorgenson and Lau (1971)] is one of the flexible functional forms which allows a variable elasticity of substitution and variable returns to scale and therefore we chose the translog specification for our econometric function.

First, we specify the embedded cost functions, one with generators fixed and all other embedded production inputs variable (for Nigeria), and the other with all embedded production inputs variable (for Indonesia). Both are specified in translog form.

When generators are fixed:

$$(12) \quad \ln c(\mathbf{w},e;k) = \alpha + \Sigma_i \beta_i \ln w_i + \tfrac{1}{2} \Sigma_i \Sigma_j \beta_{ij} \ln w_i \ln w_j + \beta_e \ln e + \tfrac{1}{2} \beta_{ee} (\ln e)^2 + \Sigma_i \beta_{ie} \ln w_i \ln e + \beta_{ke} \ln k \ln e + \Sigma_j \beta_{kj} \ln k \ln w_j + \beta_k \ln k + 1/2 \beta_{kk} (\ln k)^2 + \epsilon_c .$$

When generators are variable, the price vector, w, includes the marginal price of generating capital (k) and the terms which include k are dropped from (12).

For the efficient estimation of the translog cost function, Berndt and Christensen (1973) suggested a system of seemingly unrelated regressions (SUR of Zellner (1962)) of the cost function along with its share equations. Differentiating (12), (i.e., applying Shephard's Lemma) yields the share equations for the fixed generators case:

$$(13) \quad S_i = \partial \ln c(\mathbf{w},e;k)/\partial \ln w_i = w_i x_i / c(\mathbf{w},e) = \beta_i + \Sigma_j \beta_{ij} \ln w_j + \beta_{ik} \ln k + \beta_{ie} \ln e + \epsilon_i$$

where w_i, w_j = prices of labor and materials;

e = firm's own production of electricity;

ϵ_c, ϵ_i = error terms in the cost and share equations;

$\Sigma_i S_i = 1$, and $\beta_{ij} = \beta_{ji}$ for all i,j (the symmetry condition).

In the variable generators case, the ln k term drops from (13) and an additional share equation, that for generators appears.

The cost function is homogenous of degree one in prices, it will therefore require the following restrictions on the coefficients:

$$\Sigma_i \beta_i = 1 \; ; \; \Sigma_i \beta_{ij} = \Sigma_j \beta_{ij} = \Sigma_i \beta_{ie} = 0.$$

Since the shares add to unity, only two share equations are independent when generators are variable, and only one when generators are fixed, so there are as many equations as there are variable factors. In the variable generators case there are 27 parameters, but 12 restrictions leave only 15 free parameters to be estimated from a system of three equations, i.e., the embedded cost function and the share equations for labor and materials. We estimate the system of equations using maximum likelihood.

The marginal cost of e can be calculated by differentiating the embedded cost function:

(14a) $$\partial \ln c(w,e;k)/\partial \ln e = \beta_e + \beta_{ke} \ln k + \beta_{ee} \ln e + \Sigma_i \beta_{ie} \ln w_i$$

in the fixed generators case, or

(14b) $$\partial \ln c(w,e)/\partial \ln e = \beta_e + \beta_{ee} \ln e + \Sigma_i \beta_{ie} \ln w_i$$

in the variable generators case.

Hence, in the fixed generators case:

(15) $$p_e = MC_e = [c(w,e;k)/e]\,[\partial \ln c(w,e;k)/\partial \ln e]$$

$$= [c(w,e;k)/e]\,[\beta_e + \beta_{ke} \ln k + \beta_{ee} \ln e + \Sigma_i \beta_{ie} \ln w_i\,].$$

or, in the variable generators case:

$$(15) \quad p_e = MC_e = [c(\mathbf{w},e)/e]\,[\partial \ln c(\mathbf{w},e)/\partial \ln e]$$

$$= [c(\mathbf{w},e)/e]\,[\beta_e + \beta_{ee} \ln e + \Sigma_i \beta_{ie} \ln w_i].$$

The marginal costs so estimated will be used, in turn, in the estimation of the primary variable cost function. The primary variable cost is:

$$(16) \quad C(\mathbf{p},Q;K) = p_L L + p_M M + c(\mathbf{w},e) + t(e_B).$$

with $c(\mathbf{w},e;k)$ replacing $c(\mathbf{w},e)$ in the case of fixed generators.

This primary cost function is specified in its translog form as follows:

$$(17) \quad \ln C(\mathbf{p},Q;K) = \alpha + \Sigma_i \beta_i \ln p_i + \tfrac{1}{2}\Sigma_i\Sigma_j \beta_{ij} \ln p_i\, p_j + \beta_Q \ln Q$$

$$+ \tfrac{1}{2}\beta_{QQ} (\ln Q)^2 + \Sigma_i \beta_{iQ} \ln p_i \ln Q + \beta_{KQ} \ln K \ln Q$$

$$+ \beta_K \ln K + \tfrac{1}{2}\beta_{KK} (\ln K)^2 + \Sigma_i \beta_{iK} \ln p_i \ln K + u_c.$$

Here,

p_i, p_j = prices of labor, price of materials and the appropriate marginal costs of e and e_B.

Q = firm's primary output, and

K = fixed primary capital excluding generators.

Differentiating with respect to prices, we get the share equations for the variable factors in the primary cost function:

$$(18) \quad S_i = \partial \ln C(\mathbf{p},K,Q)/\partial \ln p_i = p_i X_i / C(\mathbf{p},K,Q)$$

$$= \beta_i + \tfrac{1}{2}\Sigma_j \beta_{ij} \ln p_j + \Sigma_i \beta_{iQ} \ln Q + \beta_{iK} \ln K + u_i,$$

where, $\Sigma_i S_i = 1$; $\beta_{ij} = \beta_{ji}$ for all i,j; and u_c, u_i are the error terms in the cost and share equations.

As before, homogeneity of degree zero in prices will require the following restrictions on the coefficients of the primary cost function:

$$(19)\quad \Sigma_i\beta_i = 1;\ \ \Sigma_i\,\beta_{ij} = \Sigma_j\,\beta_{ij} = \Sigma_i\,\beta_{iQ} = \Sigma_i\,\beta_{iK} = 0.$$

There are 48 parameters but the 21 restrictions will leave only 27 free parameters to be estimated from a system of four equations. Berndt and Wood (1975) have also shown that parameter estimates are invariant with the choice of the share equations. Thus, any three share equations can be chosen to form a system of four equations along with the cost equation. Since the errors u_c and u_i are assumed to be uncorrelated and all right hand side variables are identical, the SUR technique can be applied to the system of 4 equations with 21 restrictions on parameters, and 7 restriction across coefficients to ensure homogeneity in prices.

Below we discuss the calculation of scale economies, own, cross price and substitution elasticities and shadow prices from the translog cost function.

(ii) <u>Scale Economies</u>

Since the translog cost function is non-homothetic and non-homogeneous in output, implying a non-linear expansion path, scale economies are calculated by the inverse of the cost elasticity of output:

$$(20)\quad \eta_{CQ} = \partial\ln C/\partial\ln Q = \beta_Q + \beta_{QQ}\ln Q + \Sigma_i\,\beta_{iQ}\ln p_i + \beta_{QK}\ln K.$$

$\eta_{CQ} > 1$ implies diminishing returns to scale, $\eta_{CQ} < 1$ implies increasing returns to scale, and $\eta_{CQ} = 1$ implies constant returns to scale. The reciprocal of η_{CQ} is defined as the degree of scale economies, SCE $= 1/\eta_{CQ}$. Scale economies are determined by input prices, by the scale of the output (ln Q), and by plant capital (ln K). Notice that this measure of scale economies in primary production does not reflect cost savings arising from scale economies in embedded production or from declining block tariffs. Alternative scale measures incorporating the cost savings stemming from such scale economies or from declining block price tariffs could be constructed.

Following Stevenson (1980), the bias (effect) of the ith input on the economies of scale is:

$$(21) \quad \partial\eta_{CQ}/\partial \ln p_i = \beta_{iQ} .$$

A positive (negative) sign implies that a specific input i is cost adding (saving). We are particularly interested in the effect of electricity prices on scale economies. The coefficient β_{iQ}, with i indicating electricity, will determine whether the increase in the price of electricity is scale-augmenting or scale-offsetting.

(iii) Own, Cross-Price, and Substitution Elasticities :

The coefficients of the cross product terms B_{ij} determine the Allen partial elasticities of substitution among inputs.

$$(22) \quad \begin{aligned} \sigma_{ii} &= (B_{ii} + \hat{S}_i^2 - \hat{S}_i)/\hat{S}_i^2, \\ \sigma_{ij} &= (B_{ij} + \hat{S}_i \hat{S}_j)/\hat{S}_i \hat{S}_j . \end{aligned}$$

σ_{ij} represents the elasticity of substitution calculated at the estimated shares ($\hat{S}_i$). A positive (negative) sign implies substitutability (complementarity). σ_{ii} is used to determine the own elasticities of input demand:

$$(23) \quad \begin{aligned} \eta_{ii} &= \sigma_{ii} \hat{S}_i , \\ \eta_{ij} &= \sigma_{ij} \hat{S}_j , \\ \eta_{ji} &= \sigma_{ij} \hat{S}_i . \end{aligned}$$

η_{ii} is the own price elasticity of demand while η_{ij} represents the cross price elasticity of demand.

In the present study, the own and cross price elasticities of demand for energy would be of special interest for policy. The technological importance of electricity can be judged by the own price elasticity of demand, the elasticities of substitution between the two electricities and the elasticities between electricity and other inputs.

For judging the implications of cross subsidization or changes in tariff structures, the own and cross price elasticities of demand for electricity, η_{ee} and η_{ei} are of relevance. Since the share of inputs S_i and S_j are different for different firms, the elasticities of substitution and the demand elasticities for inputs can be calculated for individual firms.

(iv) Shadow Prices of Electricity Inputs

Shadow prices represent a firm's marginal willingness to pay for the use of inputs. We know from economic theory that a competitive firm, in equilibrium, pays each input its value of marginal product. Following Berndt, Fuss and Waverman (1973), the shadow price of an input can be calculated by estimating a "restricted" cost function holding the quantity of the input as quasi-fixed. The derivative of the restricted cost function with respect to the quasi-fixed input is the value of its marginal product to the firm. Should a firm increase the quasi-fixed input by one unit, holding the output and other input prices constant, the firm would have to adjust its other inputs, to keep its output constant. The firm's variable cost of the other inputs would decrease by the value of the input's marginal product. The negative of this value of marginal product is commonly known as the "shadow price" of the quasi-fixed input. In our case, the shadow price of purchased electricity, e_B, can be calculated by estimating a restricted cost function of the form

$$(24) \qquad C(\mathbf{p}, Q; K, e_B) = C[p_L, p_M, p_e\ Q; K, e_B].$$

where C is here defined as the variable cost of production excluding the cost of purchased electricity. Electricity purchased, e_B is fixed for each firm, but variable across the firms. If the actual price of purchased electricity were equal to its shadow price, SP_{eB}, at the fixed level of e_B, the firm (if left unrestricted) would choose to purchase just that restricted quantity of electricity (see Murray, 1988).

The shadow price of publicly supplied electricity (from 24) would be:

$$(25) \quad SP_B = - \partial C/\partial e_B .$$

The translog specification of the restricted cost function (24) is:

$$(26) \quad \ln C(\mathbf{p},Q;K,e_B) = \alpha + \Sigma_i \beta_i \ln p_i + \tfrac{1}{2}\Sigma_i\Sigma_j \beta_{ij} \ln p_i p_j + \beta_Q \ln Q$$
$$+ \tfrac{1}{2}\beta_{QQ} (\ln Q)^2 + \Sigma_i \beta_{iQ} \ln p_i \ln Q + \beta_K \ln K + \tfrac{1}{2}\beta_{KK} (\ln K)^2$$
$$+ \Sigma_i \beta_{iK} \ln p_i \ln K + \beta_B \ln e_B + \tfrac{1}{2}\beta_{BB} (\ln e_B)^2 + \Sigma_i \beta_{iB} \ln p_i \ln e_B$$
$$+ \beta_{KQ} \ln Q \ln K + \beta_{BQ} \ln Q \ln e + \beta_{BK} \ln K \ln e_B + u_c.$$

Since there are three prices, p_L, p_M, and p_e, only two share equations will be independent.

$$(27) \quad S_i = \partial \ln C(\mathbf{p},Q;K,e_B)/\partial \ln p_i = p_i X_i /C(\mathbf{p},Q;K,e_B)$$
$$= \beta_i + \Sigma_j \beta_{ij} \ln p_j + \beta_{iQ} \ln Q + \beta_{iK} \ln K + \beta_{iB} \ln e_B + u_i$$

Where p_i and p_j are any two of the three prices.

We can determine the shadow price of e_B by manipulating the derivative of (26) with respect to $\ln e_B$:

$$(28) \quad \eta_{c\,B_B} = \partial \ln C(\mathbf{p},Q;K,e_B)/ \partial \ln e_B$$
$$= \beta_B + \beta_{BB} \ln e_B + \Sigma i\, \beta_{iB} \ln p_i + \beta_{BQ} \ln Q + \beta_{BK} \ln K$$

$$(29) \quad SP_B = - (C/e_B)\eta_{c\,B} \qquad \text{(where } i,j = L,M,e\text{)}$$

IV. ESTIMATION RESULTS

(i) The Nigerian Sample

The project's establishment survey included 179 firms of various sizes. It was found that 7.8% of the surveyed firms were captive to NEPA and did not produce any power on their own. Another 2.8% were self sufficient and used their own generated power exclusively. 89.4% of the sampled firms (160 firms) used both, public power and internally generated power. As an aggregate, these firms internally generated about 32% of their power needs. The proportion of total electricity that is internally generated varies across firms from 0.14% to 96%. The present study is limited to a sample of 131 firms which produce and purchase non-negligible amounts of electricity and for which we have clean data.

ii) Indonesian Sample

The project's establishment survey included 290 firms of various sizes. 41% of the surveyed firms were captive to PLN and did not produce any power on their own; none used their own generated power exclusively. The remaining 59% of the firms (171 firms) used both public power and internally generated power. In aggregate, these firms internally generated about 47% of their power needs; the average ratio of internally generated electricity to total electricity use was 28%. The percent proportion varied across firms from 0.1% to 99.9%. The present study is limited to the sample of 118 firms which use both public and embedded electricity in non-negligible amounts and for which we had clean data.

(iii) The Thai Sample

The project's establishment survey included 300 Thai manufacturing firms, only 18 of which had their own generating capacity. Another 32 observations were lost due to missing values, leaving 250 observations for the econometric analysis.

(iv) Estimation of the Nigerian Embedded Cost Function

To estimate the embedded cost function with generators fixed, as we assume to be the case in Nigeria, we need two prices: the price of labor used in embedded production (wage rate) and the price of materials. In Nigeria, the present value of generators appears as the fixed capital input (k) in the variable cost function, and a price for capital is not needed.

For the price of labor, the total wage bill in electricity production is divided by the number of workers employed to run the generators. Since we had no measurement of either the price or the quantity of materials, but only of material expenditure, we needed in Nigeria a proxy for either quantity or price to infer the other from expenditure. We chose the capacity of the firm's generators as a proxy for the quantity of materials needed to generate electricity. We believe the errors in variables induced by this procedure are small relative to the variations in materials prices across the regions from which firms are sampled. Thus we measure the price of materials for the ith firm as:

(30) $w_{mi} = M_i / KVA_i$,

where M_i is expenditure on materials.

The Nigerian embedded variable cost function with generating capital fixed is therefore:

(31) $c(w,e;k) = c(w_l,w_m,e;k)$.

The stock of generating capital (k) is defined by the present value of generators and accessories (PVG). In order to incorporate the linear homogeneity conditions, we normalized the cost and all other prices by the price of labor [Berndt, and Wood(1975)]. The set of three equations, the embedded cost equation and the share equations, were estimated by maximum likelihood. The estimates of the Nigerian embedded cost function are shown in Table 1. All the coefficients are significant. The coefficient of capital is positive and highly significant. To measure the goodness of fit, we used the coefficient of correlation between the actual dependent variable and its predicted value. For the cost function it is 82% and for the share equation 70%.

The monotonicity condition, which requires that estimated input cost shares be positive was satisfied for all the observations. The elasticity of substitution between labor and material is positive and low (σ_{lm} = 0.450) implying poor substitutability.

The estimated function is non-homothetic. This means that the Rate of Technical Substitution (RTS) between any two inputs in embedded production is not independent of the scale of output of electricity. The cost elasticity of e, which measures the percent change in variable cost with respect to one percent change in output is:

$$(32) \quad \eta_{ce} = \partial \ln c(w,e;k)/\partial \ln e = \underset{(4.626)}{0.1676} + \underset{(4.638)}{0.0312} \ln(w_m/w_l)$$

The cost elasticity, for the whole sample, is 0.25587. This means that the greater the electricity production, implying also larger generators, the lower the average cost of electricity production. From equation (32), it can be seen that a decrease in the price of materials, or an increase in the wage, would lower the cost elasticity.

As discussed in the earlier sections, the electricity produced internally becomes an

TABLE 1

PARAMETER ESTIMATES OF NIGERIAN TRANSLOG EMBEDDED COST FUNCTION

Variables	Coefficients t-ratios
Intercept	-2.4829 (-8.458)
$\ln [w_m/w_l]$	0.2983 (7.725)
$\ln k$	0.4021 (7.715)
$\frac{1}{2} [\ln w_m/w_l]^2$	0.1045 (14.649)
$\ln k . \ln [w_m/w_l]$	-0.00002 (-4.570)
$\ln e$	0.1676 (4.626)
$\ln e . \ln [w_m/w_l]$	0.0312 (4.638)
# of Obsevations	131

embedded (internally produced) input in the primary production process. The marginal cost, MC_e, becomes the unit price of electricity in primary cost estimation. Hence,

(33) $MC_e = \eta_{ce}\ c(\mathbf{w},e)/e;$

showing that he marginal cost of electricity varies with the cost elasticity and with the average cost of production c(w,e)/e. Since the average cost is declining in Nigeria ($\eta_{ce} < 1$), there are significant economies of scale in embedded production in Nigeria, $\partial^2 c(\mathbf{w},e)/\partial e^2 < 0$ and the marginal cost of e in Nigeria is below its average cost of production.

(v) Estimation of the Indonesian Embedded Cost Function

The Indonesian data did not prove rich enough to support estimation of a translog cost function for embedded electricity. No price terms proved significant in estimation. Since the key purpose of the embedded cost function is to provide estimated marginal cost of own generated electricity, we chose to tackle the problem more simply: we regressed variable embedded costs (labor, materials, and maintenance) against output, wage and material price, all measured in logs. We found significant marginal cost differences by geocode, suggesting that geographic factor price differentials not captured by our price variables may affect firms' costs. Table 2 contains the results of this regression. Notice that in all regions there is strong evidence of increasing returns to scale in the production of own electricity. The estimated regional cost elasticities with respect to output were robust to the inclusion of industry code dummies. The scale elasticities implicit in Table 2 do not differ substantially from the scale elasticities obtained from specifications that included factor prices.

The cost elasticity of own electricity production in each locale in Indonesia can be read directly from Table 2. The marginal cost of own electricity in each locale is estimated by

TABLE 2

PARAMETER ESTIMATES OF INDONESIAN EMBEDDED COST FUNCTION

Variables	Coefficients (t-ratios)
Intercept	9.803 (3.821)
ln $[w_m]$	0.019 (0.579)
ln $[w_l]$	0.194 (1.139)
ln e *(Jabotabek site dummy)	0.489 (9.900)
ln e * (Other site dummy)	0.405 (8.902)
# of Obsevations	118

applying (33). As in Nigeria, there are considerable economies of scale in embedded electricity production in Indonesia, and the marginal cost of embedded electricity in Indonesia is below its average cost of production.

(vi) Declining Block Price Tariffs for Bought Electricity

Quantity discounts to large users are built into both the NEPA and PLN tariffs, $t''(e_B) < 0$. To empirically demonstrate this, we specified the marginal tariffs [marginal cost] for purchased power to follow the form:

$$(34) \quad t(e_{Bi}, \varepsilon_i) = B\,(e_{Bi})^{\beta}\,\varepsilon_i, \qquad 0 < \beta < 1$$

In Nigeria, we estimated this to be:

$$(35) \quad \ln t_i = \underset{(-3.30)}{-0.9754} + \underset{(15.7)}{0.75633} \ln e_{Bi} + \ln \varepsilon_i \qquad [R^2=58.7\%].$$

In Indonesia, we obtained:

$$(36) \quad \ln t_i = \underset{(25.02)}{5.561} + \underset{(51.27)}{0.95063} \ln e_{Bi} + \ln \varepsilon_i \qquad [R^2=.95].$$

with t-statistics in parentheses.

From these relationships, we calculated the marginal costs of e_B in Nigeria and Indonesia. Obtaining

$$(37) \quad MC_B = 0.75633\,[\,t_i / e_{Bi}]$$

and

$$(38) \quad MC_B = 0.95063\,[\,t_i / e_{Bi}],$$

respectively.

As explained in the introduction, these declining block price tariffs are probably inappropriate. When outages and voltage fluctuations force firms to use their own electricity, not all firms are equally affected. Smaller firms, with higher average production costs for own electricity as estimated above, incur greater average and marginal costs than do larger firms who can produce their own electricity more cheaply. Social costs of production could be reduced by reducing smaller firms' reliance on their own electricity, even if that comes at the cost of increasing larger firms' reliance on their own electricity.

Since many outages and voltage fluctuations are spurred by high levels of system usage, reducing the large firms' demand for purchased power through higher electricity prices would increase the availability of bought electricity for small firms, and would thereby increase economic efficiency. Below, we present evidence, wholly consistent with our unsurprising estimates of scale economies in electricity production, that smaller firms do indeed have higher shadow prices for purchased electricity.

(vii) Estimation of the Primary Cost Functions for Nigeria and Indonesia

In this section we present the estimation results for the Nigerian and Indonesian restricted primary cost functions (26) and their input cost shares (27). To estimate the model, we need three prices: the price of labor in primary production, the price of primary intermediate inputs, and the marginal cost of e (MC_e). We also need the quantities of primary capital and purchased electricity (e_B).

The marginal cost of own electricity we calculate from the already estimated embedded cost functions. The price of labor is calculated as the wage bill divided by the number of workers in primary production and the price of materials is calculated as the price of the intermediate input on which the most is spent (which input varies from industry to industry and maybe even from firm to firm, introducing an inevitable index number problem). The capital input, which is fixed in the short run, includes the value of plant and equipment, machinery including buildings but excluding land. The output is measured as the value of output in thousands of naira in Nigeria and in rupiah in Indonesia.

For purposes of estimation, costs in the restricted primary cost functions are computed as if the operative marginal prices for own electricity were constant (average-equal-to-marginal) prices. (See the discussion of "mythical costs in Section II. The coefficient estimates for our models are not sensitive to our decision to use as our dependent cost variable the theoretically correct "mythical" costs instead of the firms' actual costs.)

From the econometric specification point of view, since MC_e, an endogenous variable, appears on both sides of the model -- on the left hand side as a component of the mythical cost and on the right hand side as an independent price -- the simultaneity may cause correlation among error terms. To solve this problem one must purge the right hand side MC_e variable with its estimated value to gain efficiency in estimation. In each country, we tried several exogenous instruments to calculate the estimated values of MC_e and MC_B but all lost too much information to be useful. Since the cost share of electricity in total cost is rather small (less than 5%), we have decided to use the actual values of marginal costs instead of their estimated values.

The estimated restricted cost function coefficients for both Nigeria and Indonesia are shown in Table 3. Both the Nigerian and Indonesian restricted cost functions are non-homothetic. The estimated translog cost function displays positive estimated shares, negative own-price elasticities and positive elasticities of costs with respect to output for 108 firms in each sample.

Because we do not estimate unrestricted primary cost functions, we cannot formally

TABLE 3

PARAMETERS OF THE

NIGERIAN AND INDONESIAN RESTRICTED TRANSLOG COST FUNCTIONS

(primary capital and purchased electricity taken as fixed)

Variables Dep. Variable: ln (C/Pl) Nigeria: 1000's of Naira Indonesia: Rupiah	Restricted Cost Function	
	INDONESIA	NIGERIA
	Coefficients (t-ratios)	Coefficients (t-ratios)
Intercept	-28.473 (-2.081)	-1.4780 (-0.804)
$\ln (p_M/p_L)$	0.5639 (1.668)	0.3424 (2.936)
$\ln (MC_e/p_L)$	0.1421 (4.109)	0.0196 (4.465)
$\ln e_N$	2.0457 (2.027)	-0.0049 (-0.019)
$\ln Q$	1.7270 (1.947)	0.5083 (1.500)
$\ln K$	0.2222 (1.352)	0.1900 (1.778)
$\frac{1}{2} [\ln e_N]^2$	0.0308 (0.286)	0.0628 (1.499)
$\frac{1}{2} [\ln(p_M/p_L)]^2$	0.0528 (7.144)	0.0914 (16.837)

$\frac{1}{2}[\ln(MC_e/p_L)]^2$	0.0007 (0.585)	0.0001 (0.313)
$\ln(p_M/p_L).\ln(MCe/p_L)$	-0.0005 (-0.603)	0.0002 (0.692)
$\ln(p_M/p_L).\ln e_N$	-0.0142 (-0.861)	-0.0118 (-0.772)
$\ln(MC_e/p_L).\ \ln e_N$	0.0004 (0.217)	0.0004 (0.801)
$\ln Q.\ \ln (p_M/p_L)$	0.0128 (0.614)	0.0488 (2.386)
$\ln Q.\ \ln(MC_e/p_L)$	-0.0061 (-2.831)	-0.0016 (-2.250)
$\ln Q.\ \ln e_N$	-.1186 (-1.711)	-0.0494 (-0.840)
$\ln K.\ \ln (p_M/p_L)$	0.0098 (0.636)	-0.0358 (-1.938)
$\ln K.\ \ln(MC_e/p_L)$	0.0006 (0.339)	-0.0001 (-0.175)
Number of Observations	118	131

assess whether purchased and internally generated electricity are substitutes or complements. However, we can offer an informal assessment. Virtually all firms who choose standby generators choose them sufficient to supply 100% of the firms' electricity needs. At any moment in time, firms could use their own electricity as either a substitute or as a complement for purchased electricity - indeed, in the field we have observed both kinds of behavior. However, when one looks at annual production, as we do here, the reality of Nigerian and Indonesian manufacturing seems to be that the two types of electricity are complements - firms who need more bought electricity also need more of their own. At root, the unreliability of bought electricity makes those who choose to be more dependent on bought electricity also more dependent on their own electricity production.

Own and Cross-Price Elasticities of Input Demand and Elasticities of Substitution -

The elasticities of substitution, and the own and cross price elasticities of input demand for Nigeria and Indonesia are shown in Table 4; the elasticities are estimated at the sample means of the explanatory variables, but the means of the firm specific elasticities are very similar to those reported. All estimated input demands functions are inelastic with respect to their own prices, and all inputs in the table are estimated to be substitutes. The estimated price elasticities from Nigeria and Indonesia are strikingly similar. Labor and materials demands are very unresponsive to changes in the marginal cost of own electricity, which is unsurprising given the extremely small share of electricity in firm's costs. The demand for own electricity is markedly more responsive to the price of materials than to the price of labor in both countries.

Table 5 presents some comparison of our estimates of these elasticities with other studies. For U.S. manufacturing, σ_{LK} varies between 0.06 to 1.01, while Pindyck (1978) estimated σ_{LK}

TABLE 4

ALLEN-UZAWA PARTIAL ELASTICITIES OF SUBSTITUTION

IN NIGERIAN AND INDONESIAN PRIMARY PRODUCTION

(At means of estimated shares)

NIGERIA

	Labor	Material	E-own
Labor	-1.421	0.536	0.846
Material		-0.216	1.034
E-own			-135.087

INDONESIA

	Labor	Material	E-own
Labor	-1.980	0.727	0.952
Material		-0.305	1.113
E-own			-45.643

TABLE 4 (cont'd)

OWN AND CROSS PRICE ELASTICITIES OF INPUTS IN PRIMARY PRODUCTION

(At means of estimated shares)

NIGERIA

Elasticity of:	**Labor**	**Material**	**E-own**
With respect to: Labor	-0.391	0.148	0.233
Material	0.385	-0.155	0.742
E-own	0.006	0.007	0.975

INDONESIA

Elasticity of:	**Labor**	**Material**	**E-own**
With respect to: Labor	-0.535	0.197	0.257
Material	0.515	-0.217	0.686
E-own	0.020	0.020	-0.943

TABLE 5

COMPARISON OF ESTIMATES OF FACTOR SUBSTITUTION ELASTICITY AND FACTOR DEMAND ELASTICITY

	Berndt & Wood (U.S.A.)	Griffen & Gregory (U.S.A.)	Pindyck a/	Berndt & Morrison (U.S.A.)	Christensen & Greene b/ (U.S.A.)	Our Study
•LK	1.01	.06	.06 to .52		.63	—
•LE	.65	.87	.72 to .87		.16	1.42/1.98
•KE	-3.22	1.07	1.02 to 1.07		.21	—
•ME	.75					1.03/1.11
'EE	-.045	-.79	-.78 to -.80	-.055	-.08	-.94/-.98
'LL	-.46	-.12	-.12 to -.27	-.34	-.22	-.39/-.54
'KK	-.50	-.18	-.18 to -.38	-.20	-.23	—
'MM	-.24			-.22		-.16/-.22
'EL	.18	.64		.42		-.23/-.26
'EK	-.18	.15		-.11		—
'EM	.46			.23		.74/.69
'LE	.03	.11	.11	.07		.00/.02
'KE	-.14	.13	.13	-.07		—
'ME				.01		.00/.02

a/ Nine industrial countries.

b/ U.S. electric power generation, E stands for fuels in their study.

for nine European countries and found it to vary between 0.06 to 0.52. Results usually show labor and electricity as substitutes, as do our results for Nigeria. Our elasticity of substitution between materials and electricity shows substitutability as in Berndt and Wood.

Cost Elasticity with Respect to Output and Economies of Scale -

The estimated cost elasticity of output, as a measure of the scale effect is less than one for all firms in both countries, implying widespread increasing returns to scale. Observing positive scale economies in the sample suggests capital market imperfections in both countries as low cost and high cost producers exist side by side. The cost elasticity is negatively and significantly related to the marginal cost of own electricity in both countries.

The Shadow Price of Purchased Electricity -

Table 6 reports the mean and median shadow prices of purchased electricity in Nigeria and Indonesia, and compares these to the mean and median tariff prices of bought electricity and to the mean and median marginal costs of own electricity. Both the shadow prices of purchased electricity and the marginal cost of own electricity substantially exceed the marginal cost of purchased electricity: firms would much prefer to buy their electricity than to produce it themselves.

If own electricity and purchased electricity were perfect substitutes in production, firms should value additional purchased electricity at the marginal cost of the produced electricity they decide to produce. In Indonesia, the mean estimated shadow price of bought electricity lies above the mean marginal cost, while the median shadow price lies below the median marginal cost. In Nigeria, both the mean and median shadow prices lie substantially above the

TABLE 6

MEAN AND MEDIAN VALUES FOR SHADOW PRICE OF BOUGHT ELECTRICITY, MARGINAL COST OF BOUGHT ELECTRICITY AND THE MARGINAL COST OF PRODUCED ELECTRICITY

NIGERIA

(Naira)

	BOUGHT ELECTRICITY		OWN ELECTRICITY
	SHADOW PRICE	MARGINAL COST	MARGINAL COST
MEAN	3.54	0.14	0.28
MEDIAN	1.00	0.06	0.11

(In the Nigerian analysis, generator costs are treated as fixed, and hence are not included in the marginal cost of own electricity.)

INDONESIA

(Rupiah)

	BOUGHT ELECTRICITY		OWN ELECTRICITY
	SHADOW PRICE	MARGINAL COST	MARGINAL COST
MEAN	2437	151	1147
MEDIAN	230	128	671

(In the Indonesian analysis, generator costs are treated as variable, and hence are included in the marginal cost of own electricity.)

corresponding marginal cost statistics. These differentials are indicative of the imprecision of our estimated cost functions. Indeed, altering the specification of the primary restricted cost functions modestly (dropping this or that insignificant variable, for example) moves the estimated shadow prices about substantially. However, that the shadow prices of bought electricity exceeds the marginal tariff price (marginal cost) of bought electricity is a robust finding across specifications.

Also robust across alternative specifications is the finding that the shadow price of bought electricity falls with the level of bought electricity. Larger firms value bought electricity less at the margin than do smaller firms. Among firms with positive shadow prices for bought electricity, the elasticity of shadow price with respect to bought electricity is -.65 in Nigeria and -.44 in Indonesia, numbers that did not vary widely across alternative specifications. These elasticities are not far from the elasticities of marginal cost of own electricity with respect to own electricity: -.44 in Nigeria and -.60 in Indonesia. In broad brush, what these numbers suggest is that firms that firms' marginal willingness to pay for publicly provided electricity varies directly with the firms' marginal cost of providing their own electricity. The shadow prices of bought electricity shifts much like the marginal costs of own electricity does. Thus, the shadow price evidence reinforces the argument for a policy shift from decreasing to increasing block price tariffs for purchased electricity. Firms that purchase smaller quantities of electricity value electricity more highly at the margin. Redistributing the limited supply of publicly provided electricity from larger purchasers to smaller would increase economic efficiency by moving the electricity from lower valued uses to higher valued uses.

(viii) Estimation of the Unrestricted Primary Cost Function for Thailand

Only 6% of Thai manufacturing firms had their own electricity generators. Clearly, Thailand's electricity utility fills the needs of industry far better than do its Nigerian and Indonesian counterparts. Thai firms experience relatively few power outages and voltage fluctuations, sparing them the need for their own.

generators and permitting them to choose whatever level of publicly provided electricity they desire. Since firms can choose the level of purchased electricity, the cost function we estimate for Thai firms is an unrestricted cost function, in contrast to the restricted cost functions estimated above for Nigeria and Indonesia. (Strictly speaking, the Thai cost function is also a restricted cost function, because we take the capital stock as given in Thailand as we do in Nigeria and Indonesia.)

Since purchased electricity is a variable input in Thailand, the cost function is unrestricted (includes the marginal price of purchased electricity, rather than the quantity). Also, there is no own electricity in the cost function. To estimate the marginal price of purchased electricity, we specify that the utility's electricity tariff is of the form (34): In Thailand, we estimated this to be:

$$(39) \quad \ln t_i = \underset{(16.719)}{1.1145} + \underset{(83.59)}{0.9249} \ln e_{B\,i} + \ln \varepsilon_i \qquad [R^2=96.1\%]$$

From (39) we calculate the marginal cost of e_B in Thailand as:

$$(40) \quad MC_B = 0.9249\ [\ t_i / e_{B\,i}]$$

Table 7 reports the estimated coefficients of the unrestricted translog cost function for Thailand. We cannot reject the hypothesis that technology is homothetic in labor, materials and electricity, conditional on the level of capital. Estimated scale economies in Thailand appear constant across firms at a level of 1.2 (cost elasticity = .83). This level of scale elasticities is much less than in Nigeria or Thailand, presumably reflecting fewer capital market imperfections in Thailand than in those other countries.

Table 8 reports the elasticities of substitution and the price elasticities of factor demands in Thailand. It is notable that in the absence of restrictions on purchased electricity, eight of nine estimated elasticities are larger in Thailand than in nearby Indonesia.

TABLE 7

PARAMETERS OF THAI TRANSLOG PRIMARY COST FUNCTION

(Primary Capital Fixed)

Dependent Variable $[C/p_L]$ in Baht	Coefficients t-ratios
Intercept	-11.538 (-17.318)
$\ln (p_M/p_L)$	-.0414 (-0.415)
$\ln (MC_N/p_L)$	0.3237 (-3.709)
$\ln Q$	0.8311 (16.299)
$\ln K$	0.1616 (2.964)
$\frac{1}{2} [\ln(p_M/p_L)]^2$	0.0129 (2.728)
$\frac{1}{2} [\ln(MC_N/p_L)]^2$	-0.0266 (3.160)

$\ln(p_M/p_L)(MC_N/p_L)$	-0.0036 (-2.688)
$\ln Q. \ln(p_M/p_L)$	-0.0010 (-.0114)
$\ln Q. \ln(MC_N/p_L)$	0.0007 (0.159)
$\ln K. \ln(p_M/p_L)$	0.0082 (0.808)
$\ln K. \ln(MC_N/p_L)$	0.0098 (2.274)
Number of Observations	250

TABLE 8

ALLEN-UZAWA PARTIAL ELASTICITIES OF SUBSTITUTION

IN THAI PRIMARY PRODUCTION

(At means of estimated shares)

THAILAND

	Labor	Material	E-bought
Labor	-2.052	0.954	2.331
Material		0.665	.906
E-bought			-20.546

OWN AND CROSS PRICE ELASTICITIES OF INPUTS

IN PRIMARY PRODUCTION

(At means of estimated shares)

THAILAND

Elasticity of:	Labor	Material	E-bought
With respect to: Labor	-0.713	0.332	0.810
Material	0.561	-0.391	0.532
E-bought	0.152	0.059	-1.342

V. CONCLUSIONS

We conclude with five major policy insights gleaned from our empirical analysis:

i) NEPA'S Tariff schedule should be revised to increase economic efficiency.

The shadow price of e_B is higher than its tariff because public supply is worth much more than what firms actually pay for these services. If the firms could purchase more electricity and produce less, they would. However, the shadow prices of e_B vary sharply by firm size; smaller firms are willing to pay more than large firms. Hence redistributing public electricity supply from large firms to small firms would improve economic efficiency. To redistribute public supply in this way would require markedly raising tariffs for large users, shifting from the current scheme of decreasing block prices to increasing block prices. Sufficiently large tariff increases for large firms would lead them to reduce their use of publicly supplied electricity, thereby reducing the congestion which is a major source of voltage fluctuations and service interruptions. Thus, raising tariffs of large firms could both redistribute electricity efficiently and improve the quality of electricity service to remaining users. (Our argument for increasing block price schedules differs from those of Scholtes (1990) and Markandya and Pemberton (1990) who show that equity concerns may make preferable increasing block price schedules for electricity in poorer countries.) The simulations reported in Anas and Lee (1995) show that the potential gains from an increasing block price tariff in Nigeria are large, while their simulations for Indonesia show only small gains to be had there. Consequently, we only recommend tariff changes in Nigeria. It is unlikely that the public supply of electricity will improve dramatically in the near future in Nigeria; the government should reap what gains it can from better pricing policies. In Indonesia, economic growth may by itself undo many of the infrastructure deficiencies firms now report; novel changes in pricing policy may be unwarranted.

An ancillary benefit of the tariff increase that we recommend would be increased revenues for NEPA.

If NEPA used these higher revenues to improve the quality of its transmission system, a further gain in efficiency might be realized. The suggested pricing schedule would offer additional benefits in the form of business and job creation because smaller firms, responsible for most job creation according to previous Bank research (Lee, 1985 and 1989), will respond favorably to lower electricity costs and higher quality electricity service. Neither higher tariffs as a source of revenue nor benefits to micro enterprises to spur job creation are nearly as important in Indonesia as they might be in Nigeria, so long as Indonesia's current economic boom is providing both revenues to government and jobs to workers.

ii) Private firms should be allowed to sell electricity to one another. This policy is already in place in Indonesia. It should be implemented in Nigeria. Large firms produce own electricity at lower marginal cost than small firms do. Allowing larger firms to sell electricity to smaller firms near them would improve economic efficiency. The efficiency gains from such a policy might well be enhanced if firms selling electricity to neighbors put competitive pressure on NEPA that resulted in improvements in NEPA electricity delivery. (Any attempts to regulate the prices on intra-firm sales, or on sales to the public utility, should be viewed skeptically in the light of Harberger's (1993) recent welfare analysis of electricity cogeneration and sale in Canada.)

iii) The marginal costs of producing own electricity are much higher than the marginal costs of purchasing public power, and probably comparably higher than the utilities' marginal cost of producing that power. Embedded electricity production encroaches on firms' productivity because embedded production diverts resources away from primary output. Costly private provision of infrastructure certainly limits the growth and expansion of firms. Were NEPA and PLN efficient, shifting electricity production from embedded production to NEPA and PLN production would harness the utilities' much greater economies of scale. In the long run, firms would reap still larger benefits as they avoided the need to replace their generators. However, until public electricity supply in these countries becomes more reliable (and in Nigeria, far more reliable), it is efficient for government to encourage internal power generation judiciously.

iv) The Indonesian government has in recent years encouraged private electricity production by offering tariff reductions on generators and by reducing the import tax on generators. Nigeria should follow Indonesia's lead in this regard. As long as the public provision of electricity remains deficient, policies should facilitate firms' efforts to overcome the inadequacies of the public system Easing price distortions and administrative hurdles on goods that firms use to ameliorate the costs imposed upon them by poor public infrastructure is one way to lessen the burden of such remedies.

v) Nigeria should follow the recent lead of Indonesia and open up the electricity markets, allowing third party vendors to participate in the provision of power (and other infrastructure services as well). Baumol and Lee (1991) suggest that there may be considerable efficiency gains from such efforts to make infrastructure markets contestable.

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